APPENDIX A
LANDFILL OFF-GAB SYSTEMS ENGINEERING TECHNICAL LETTER
DESIGN CONSIDERATIONS

1.0 INTRODUCTION

Landfill gas (LFG) that is generated from the decomposition of municipal solid waste (MSW) in a landfill consists of a mix of approximately 50 percent methane (CH_4) and 50 percent carbon dioxide ($C0_2$). Trace amounts of oxygen (O_2), nonmethane organic compounds (NMOC) whose principal components are hydrogen sulfide (H_2S), and reactive organic gases (ROGs) may also be present.

There are increasing concerns with the emissions of LFG and its contribution to air pollution since volatile emissions from landfills represent a major source of organic contaminants entering the atmosphere. The concerns are based on the following:

- CH_4 gas is highly combustible, making it a potential hazard in the landfill environment, or in structures on adjacent properties;
- LFG is capable of migrating significant distances through soil, thereby increasing the risk of explosion and exposure. Serious accidents resulting in injury, loss of life and extensive property damage may occur where landfill conditions favor gas migration;
- As LFG is produced, the pressure gradient upward may create cracks and disrupt the geomembrane in the landfill cover;
- CH_4 gas is an asphyxiant to humans and animals in high concentrations;
- Migrating gas may result in other adverse effects such as stress to vegetation, by lowering the 02 content of soil gas available in the root zone;
- Gas generated at landfills and vented to the atmosphere frequently emanates nuisance odors causing annoyance to individuals residing nearby;

- Emissions of NMOC and ROG, or ozone precursors contained in LFG, may be contributing to the degradation of local air quality. Where landfills contain sources of sulfur, such as shredded construction/demolition material and gypsum board, there is increased potential for liberation of H_2S which is noxious at low concentrations and can cause asphyxiation, if gas is migrating to enclosed areas;

- Vinyl chloride from landfills has been found to be present in substantial concentrations in LFGs and has been detected in off-site conduits, representing health and safety concerns. Vinyl chloride is found in municipal as well as commercial solid waste landfills;

- CH_4 gas, one of the "green house gases", contributes to the possibility of global warming of the earth's climate; and

- Uncontrolled LFG is a loss of potential resources; instead it can be a satisfactory fuel for a wide variety of applications. Many types of energy equipment designed for conventional fuels can operate on LFG with the power output reduced about 5 to 20 percent [(1)]

Currently, federal and state environmental agencies are developing stringent regulations for air emissions from municipal and industrial landfills. The United States Environmental Protection Agency (EPA) has proposed regulations for control of air emissions from MSW landfills, based on Section 111 the Clean Air Act (CAA)[(2)]. The new regulations require gas management systems as a component of the landfill final cover.

1.1 PURPOSE

The purpose of this Engineering Technical Letter (ETL) is to provide information and procedures necessary for the design of systems to monitor, collect, characterize, transport, and treat off-gas from municipal, industrial and hazardous waste landfills. The ETL describes and evaluates various LFG emission control techniques and presents design procedures relative to specific functional requirements. The ETL is intended to aid the designer and others who possess some knowledge of hydrogeology, civil engineering, chemistry, mathematics, materials science, and who have some design experience to select the most effective solutions to problems of controlling LFG.

1.2 SCOPE

The following topics are discussed in this ETL:

- Chapter 1, Introduction, presents the origin of LFG, reasons why control is necessary, the purpose of this ETL, the scope of this ETL, and LFG control issues;

- Chapter 2, Theory of Landfill Gas Emissions, discusses the mechanisms of LFG generation, factors affecting LFG generation, transport mechanisms, and factors affecting LFG movement/migration, LFG characteristics, condensate characteristics, mathematical gas flow, estimation of LFG production, and different LFG estimation models;

- Chapter 3, Landfill Off-gas Applicability, discusses LFG collection, LFG disposal and treatment for energy recovery, along with advantages and disadvantages of each technology;

- Chapter 4, Design Considerations, discusses design parameters of LFG collection systems, LFG treatment systems, LFG condensate treatment methods, LFG purification systems, gas measurement systems, instrumentation, monitoring, control, and utility requirements;

- Chapter 5, Regulatory Requirements, discusses current and proposed regulations applicable to air toxic rules under the CAA, local air toxic rules, and proposed global warming legislation;

- Chapter 6, Environmental Issues, discusses adverse effects of LFG emissions and benefits of LFG control;

- Chapter 7, Construction Materials and Installation, discusses construction materials for gas collection systems, treatment equipment, condensate collection and treatment systems, construction criteria and quality assurance (QA) guidance;

- Chapter 8, Operating Conditions, discusses operation safety, process interferences, operation concerns, system start-up, training, maintenance requirements, and operation labor requirements;

- Chapter 9, Design and Construction Package, discusses design analysis, design documents, drawings and specifications for bidding and construction, guide specifications, and operations and maintenance; and

- Appendices present design calculations, a check list for design documents, bibliography, design examples and definitions of terms and acronyms.

1.3 REFERENCES

The information used in the development of this ETL is listed in Appendix D, Bibliography.

1.4 BACKGROUND

Sanitary landfilling is the primary method for disposal of municipal and household solid waste or refuse in the United States (U.S.). The daily per capita quantity of solid waste generated for military troop facilities is estimated at 2 to 3 kgs (4 to 6 lbs) of combined refuse and garbage [3] . Hazardous waste amounts vary with the locations and military activities. Based on the effective population of 5000, which is the sum of the resident population and non-resident employees at a typical military base, the amount of solid waste or refuse landfilled annually by each base is about 5,000 tons. The quantity and quality of LFG generated in a landfill depends on the types of solid wastes that are decomposing. LFG is produced at a volume of approximately 3 to 6 cubic feet per pound of municipal solid waste [(2)].

Experience with landfill-generated CH_4 recovery and utilization has shown that installation of LFG collection systems has reduced LFG emissions and improved local air quality. LFG is being increasingly developed as an energy resource and is currently recovered commercially at more than 70 sites in the U.S. and a number of sites in the United Kingdom and Europe [(1)].

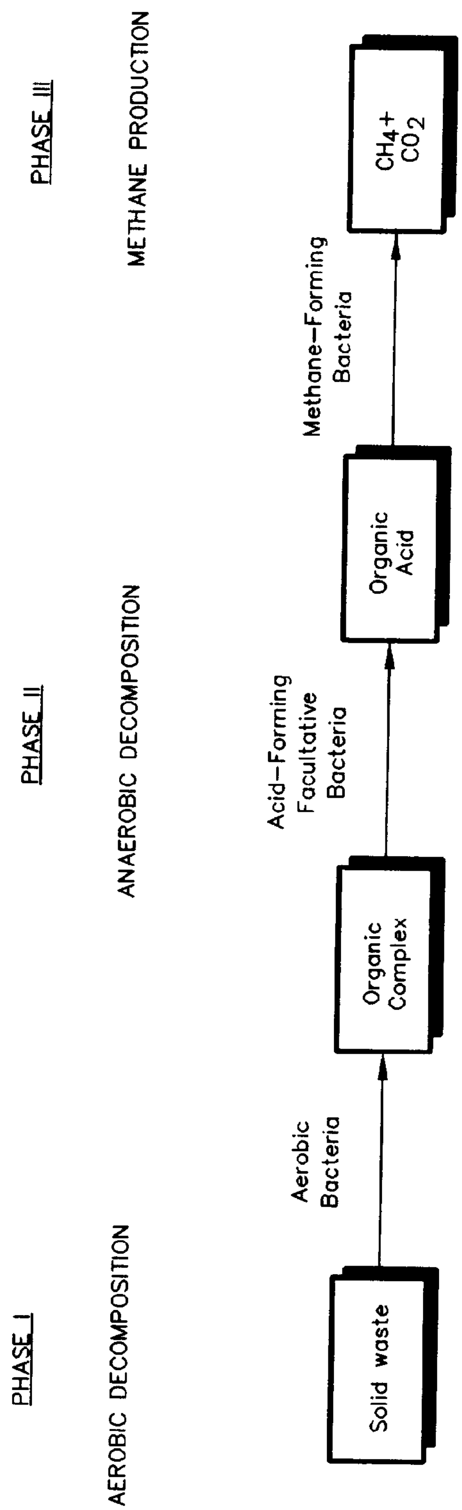
1.5 THEORY

A landfill can be described as an engineered burial of solid wastes that are subsequently degraded by chemical reactions and biological activities. The biological degradation or decomposition of solid wastes generates CH_4, and $C0_2$ along with traces of other compounds. The biological decomposition of solid waste follows three distinct phases, as illustrated in Figure A-1.

Phase 1. The microorganisms slowly degrade the complex organic portions of the waste using the O_2 trapped during the landfilling process to form simpler organic compounds, $C0_2$ and water. This phase is termed aerobic decomposition.

Phase 2. After the O_2 is fully consumed, facultative bacteria grow and decompose waste into simpler molecules such as hydrogen, ammonia, $C0_2$, and organic acids. This second phase is step one of the anaerobic phase.

Phase 3. In the third decomposition phase (step two of anaerobic phase), CH_4-forming bacteria (methanotrops) utilize $C0_2$, hydrogen, and inorganic acids to form CH_4 gas and other products.



THREE-STAGE BIOLOGICAL DECOMPOSITION OF SOLID WASTE

FIGURE A-1

Chemical reactions between wastes placed in landfills may also take place producing volatile constituents.

1.6 OBJECTIVES

The overall objective of this ETL is to aid in the design of LFG control systems; i.e., extraction, disposal, treatment and utilization of LFG for energy recovery.

Sub-objectives include:

- Review and analyze available knowledge of the LFG-generation process; estimate production rate, and specific characteristics that influence the production rate;
- Examine and analyze alternative collection, monitoring, treatment, processing, and utilization methods of LFG to achieve economic viability;
- Review and evaluate the landfill off-gas design and operation techniques including condensate management to aid in selecting an optimum system design for a specific site; and
- Provide design examples for guidance.